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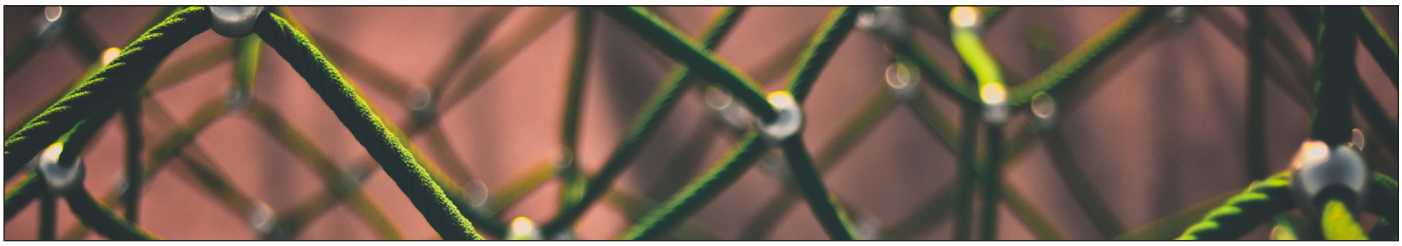

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Infrastructure and technology-enhanced learning: Context, agency, multiplicity

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Abstract

The notion of infrastructure is surprisingly under-theorised in studies of technology-enhanced learning (TEL), despite efforts to encourage models of infrastructure as social and relational. In this reflective paper, I discuss how I used theory about infrastructure derived from Science and Technology Studies (STS) and cultural anthropology ('infrastructural theory') to explain how academic librarians produce knowledge via Twitter in a research-intensive university in the United Kingdom. Infrastructural theory posits infrastructure as contingent, value laden, performative and remarkably fragile. Using a theoretical framework devised from the tenets of infrastructural theory, I found that academic librarians create knowledge infrastructures via Twitter that mobilise notions of invisibility, are rooted in professional values and aim for wide reach across the scholarly community. I conclude the paper with a discussion of how infrastructural theory can complicate existing approaches to infrastructure in TEL studies by drawing attention to the heterogeneity and agency inherent in infrastructure and how infrastructure and social practices are mutually constitutive. I further argue that infrastructural theory should be at the heart of design considerations for TEL and that the time is ripe for more robust theorisation of infrastructure in TEL.

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1. Introduction

> A lesson of infrastructure is that it surfaces the social conditions and times in which it is sited; thus, it demonstrates as much about our historical and cultural attentions in a particular moment and place as it does about the thing itself. (Howe et al., 2016, p. 552)
>
> Foregrounding the infrastructure, analytically speaking, allows the examination of otherwise unnoticed or naturalized forms of marginalization, exclusion and inequality. (Hine, 2020, p. 27)

Given the near ubiquity of digital platform infrastructures for teaching and learning (Ludvigsen & Steier, 2019) and serious ethical concerns over dataveillance in university settings (Komljenovic, 2019; Williamson, 2017, 2018), the notion of infrastructure as a social phenomenon is surprisingly under-theorised in the literature of technology-enhanced learning (TEL), despite the efforts of a handful of researchers to encourage social and relational models of infrastructure. If infrastructure is foregrounded at all in most TEL studies, it is generally approached uncritically as support systems discrete from, and simplistically in service or opposition to, teaching and learning practices. In such framings, infrastructure is a black box, mute and closed to investigation.

In this article, I argue that infrastructure is a crucial aspect of the social context of TEL and that conceptualising infrastructure as monolithic support systems erases the human work and values at the heart of infrastructures for teaching and learning (cf. Hine, 2020; Johanes & Thille, 2019; Seaver, 2018). More than 20 years of theorising about the nature of infrastructure in the fields of Science and Technology Studies (STS) and cultural anthropology (hereafter, 'infrastructural theory'), however, offers a different model of infrastructure as contingent, value laden, performative and remarkably fragile and opens possibilities for considering the imbrication of infrastructure and TEL practices. Such theory also, as I will discuss, opens possibilities for contesting infrastructural systems that are seemingly unassailable.

In this reflexive piece, I discuss my use of infrastructural theory in my PhD study to explain how academic librarians produce knowledge via Twitter in a research-intensive university in the United Kingdom. My study draws attention to the heterogeneity and agency inherent in infrastructure and offers a vocabulary for helping shift discussions in TEL from what infrastructure supports to what it constitutes socially. In so doing, I position my work within larger efforts of TEL to highlight contextual forces that shape education and technology practices (Castañeda & Selwyn, 2018). My PhD study started from a position advocated by Bayne (2015) and others that TEL practices are complex constellations of people and technology. To tease out the effects of academic librarians' Twitter practices on knowledge production in higher education (HE), I was particularly interested in focussing on the second recommendation in Bower's (2019) list of seven aspects of educational technology contexts: "Understanding ways in which technological beliefs, knowledge, practices and the environment (including the sociopolitical environment) mutually influence one another with relation to educational technology usage" (p. 1044).

It is important to note, however, that approaches already exist in the TEL literature to describe the social conditions of educational-technology use including social constructivism (Hamilton & Friesen, 2013), activity theory (Bower, 2019), sociomaterialism (Fenwick et al., 2011) social construction of technology (A. Jones & Bissell, 2011) and socio-technical information networks (Walker & Creanor, 2009). All are useful for illuminating what C. Jones et al. (2006) refer to as the meso level of analysis, or "the place of social practice…in which broader social processes are located in small, local group activity" (p. 37). However, with my interest in knowledge production and libraries' historically infrastructural role in HE (Borgman, 2003), I found infrastructural theory – particularly the notion of *knowledge infrastructures* (Karasti et al., 2016a), which I will discuss fully below – to be highly relevant to my study. Infrastructural theory draws attention to the distributed influences of infrastructure, an entity often black-boxed in discussions of educational technology. Situated in traditions of sociomaterialism and actor network theory, the body of infrastructural theory discussed in this study proposes a significant and mutually-constitutive relationship between infrastructure and social practices (Lee & Schmidt, 2018, p. 195).

Trowler (2012) appeals for greater reflectivity in the role and uses of theory in educational research. Through a discussion, therefore, of how I conceptualised, modified and applied infrastructural theory in my project, I hope to lay bare the processes by which I used theory to make claims about my research (Ashwin, 2012, p. 947), i.e., how I analysed empirical data, drew conclusions and ultimately developed theory for future use. I start this article, therefore, by situating my study in a brief review of the literature about social media, academic libraries and HE, followed by longer sections describing the tenets of infrastructural theory, how they helped explain my research data and their implications

for understanding the social, institutional and technological contexts of TEL.

2. Social media, academic libraries and higher education

In my study, I define social media as "web-based services that allow individuals, communities, and organizations to collaborate, connect, interact, and build community by enabling them to create, co-create, modify, share, and engage with user-generated content that is easily accessible" (McCay-Peet & Quan-Haase, 2017, p. 17). Importantly for my study, Greenhow et al. (2019) note that "online social networks [can] facilitate new ways of creating, manipulating, representing and distributing knowledge" in HE (p. 988). These new forms of knowledge production are the principal focus of my study, especially in terms of the interplay of technology, politics and values woven into such knowledge production.

Research in the library-practitioner literature has charted the rising use of social media, particularly Twitter, by academic libraries (Collins & Quan-Haase 2014; Godwin, 2011) and regularly discusses its benefits and best practices (Deodato, 2018; Trucks, 2019). In the library-practitioner literature – the TEL literature rarely mentions libraries – empirical studies of librarians' Twitter practices tend to frame such work as service promotion, overlooking the relationship between technology and librarians' professional practices. Such studies focus either on the content of librarians' social media work or the success of such work for engaging students and faculty. For studies that focus on content, the most common finding is that academic libraries use Twitter, in the main, to promote events, services, study spaces and collections (Al-Daihani & Abrahams, 2016). However, the studies also find that academic libraries' tweeting entails a strong theme of attempting to create scholarly communities of researchers (Stvilia & Gibradze, 2014; Harrison et al., 2017). For studies that focus on engagement, the most common finding is that despite libraries' goal to prompt conversations with students and researchers via Twitter, libraries tend to broadcast information more than foster dialogue (Deodato, 2014; M. J. Jones & Harvey, 2019). No studies in the library-practitioner literature, however, frame librarians' Twitter practices as producers of knowledge. This is curious given that, as discussed above, TEL theorists note that social media constitutes a burgeoning area of knowledge production in HE (Greenhow et al., 2019; Lang & Lemon, 2014). The library-practitioner literature, moreover, widely argues that contemporary academic libraries, in addition to being for the storage and retrieval of information and educating users about information literacy, are *creators* of knowledge, particularly in the area of research support (Dempsey, 2017). If libraries use Twitter to disseminate information and encourage scholarly community, it seems logical to conclude they are producing knowledge for university.

Two further trends in HE form the backdrop for my study. The first is the adoption of social media for pedagogical purposes. Bower (2016) proposed a typology of pedagogical uses of social media, noting the ability of social media to enhance "communication, productivity and sharing" for students (p. 763). Researchers of social media and HE note that social media use can increase student engagement and criticality (Weller & Strohmaier, 2014), but there is little consensus regarding its benefits to students (Tang & Hew, 2017). In terms of the priorities of my project, studies that explore how social media could be used for teaching purposes tend to position Twitter as a tool with pedagogical affordances and delimit best practices for its use (e.g., Junco et al., 2013). Such studies rarely explore the broader political context of social media (e.g., Wyatt et al., 2016) or the ontological effects of social media use on students' identities (e.g., Ross, 2014).

The second key trend discussed in the TEL literature is the role of social media in faculty research practices (Greenhow et al., 2019), such as networks of collaboration engendered by social media technologies (Veletsianos & Kimmons, 2013). Researchers have explored the importance of Twitter in relation to informal scholarly communication (Quan-Haase et al., 2015) and expression of academic identity (Veletsianos & Kimmons, 2016), but some voice concerns about the platform's power dynamics and issues of privacy (Gregory & Singh, 2018). Importantly for my study, the use of Twitter as an informal learning space to create and curate knowledge beneficial to academics has been explored as a significant aspect of knowledge production (Lang & Lemon, 2014; McPherson et al., 2015). My study drew similar conclusions, along with noting analogous ontological effects on communities of scholars – topics that Greenhow et al. (2019, p. 998) argue need more robust theorisation in the TEL literature.

The aim of my PhD study, therefore, was to expand discussions of librarians' social media use by exploring how social media – particularly Twitter – has intertwined dynamically with librarians' shifting roles, thus introducing new dimensions to librarians' knowledge work in the university. In the following sections I discuss my study design and why I found infrastructural theory valuable for untangling such practices.

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3. Methods and role of theory

My study participants were six librarians at the same university who are regular tweeters for their libraries. My specific data-gathering methods included two rounds of semi-structured interviews, participant diaries, analysis of selected Twitter analytics and a focus group. The diaries provided a longitudinal perspective on the daily work and decision making of librarians' Twitter practices, while the focus group at the end of the data-collection period was a strategy to further deepen and validate findings.

In terms of how I conceptualised theory in my study, my definition aligns with Trowler's (2012) who asserts that:

> It [theory] illuminates 'reality' – simplifying and identifying what is important and what not, suggesting how things relate to each other, highlighting causality, providing explanations. ... Explicit theory, then, surfaces sets of propositions and so renders them amenable to critique. It generates hypotheses that can then guide questions, methodology and methods. ... Theory can function to take research beyond being simply descriptions. (p. 276)

I further wanted my use of theory to cause an element of surprise, or what Willis and Trondman (2002, p. 399) call "'aha' effects" that resonate with readers emotionally. My goal, therefore, was to use theory to interrogate and explain my data in a way that described aspects of academic librarians' work missing from existing studies, but also intuitively recognisable to readers once exposed. I was also not explicitly testing theoretical propositions or setting out to develop theory *per se*. However, as I discuss in the next section, both happened along the way as I strove to apply concepts of my theoretical framework to my empirical data. Analysing my data, looking for theories, re-examining my data, developing a theoretical focus, etc., was circular and iterative, or what Clegg (2012) refers to as "the messy and complex endeavour of theorising and the dialectic between theory and data, which is not reducible to either inductive or deductive logic" (p. 407).

4. Infrastructural theory

Popular conceptions of infrastructure posit it as an unnoticed and enduring substrate, such as bridges or the Internet, enabling the circulation of goods and information (Carse, 2016). In the fields of STS and cultural anthropology, however, infrastructure, though still considered a system of support, is theorised as contingent, value laden, performative and remarkably fragile (Appel et al., 2018). In other words, phenomena that we take as 'just there' and invisibly supportive of modern life are seen to be constituted of a myriad of mundane practices and political decisions rooted in situated human values (Star, 2002). From this perspective, infrastructure is a constantly emerging and contingent accomplishment that – importantly for my study – exerts ontological effects on its designers and users:

> Viewed as open-ended experimental systems that generate emergent practical ontologies, infrastructures hold the potential capacity to do such diverse things as making new forms of sociality, remaking landscapes, defining novel forms of politics, reorienting agency, and reconfiguring subjects and objects, *possibly all at once*. (Jensen & Morita, 2017, p. 620, emphasis in original)

Infrastructure, in other words, is more than just "matter that enable the movement of other matter," it is "the relation between things" (Larkin, 2013, p. 329) and windows onto social and political change (Howe et al., 2016, p. 552). Infrastructural theory, therefore, with its emphasis on invisible and mundane work practices that lead to larger social effects, intuitively felt like a good fit for my study which aimed to complicate discussions about academic librarians' social media work in the contemporary university.

Three aspects of infrastructural theory were particularly compelling for my project: the notions of *knowledge infrastructures*, *infrastructuring* and *infrastructural inversion*. Firstly, *knowledge infrastructures* (KIs) are defined as "networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds" (Edwards, 2010, p. 17). Monteiro et al. (2014) assert that the distinguishing feature of knowledge infrastructures is their "epistemic machinery" (p. 8), i.e., their ability to produce new forms of knowledge. It is not that other forms of infrastructure cannot do this, it is just that the term more directly implies a special focus on how infrastructures "exert effects on the shape and possibility of knowledge in general" (Edwards et al., 2013, p. 23). Examples of KIs can include databases, taxonomies and scientific monitoring instruments (Karasti et al., 2016a-d). The more I learned about infrastructural theory, the more I felt that librarians' Twitter practices could be interpreted and usefully explored as KIs.

Secondly, *infrastructuring* is a concept stemming from design considerations in the information systems literature (Pipek & Wulf, 2009). Infrastructuring, as a verb, conveys the idea that KIs are accretions of technologies and social relations (Anand, 2015) – something always in the making

– which in turn necessitate ongoing repair and maintenance (Karasti et al., 2018). Importantly for my project, studies of infrastructuring stress that work to maintain infrastructures is laden with values reflecting care towards technology and hopes for the future (Houston et al., 2016). Infrastructuring further implies that, through repair and maintenance, infrastructure exerts an influence on its creators, users and its own technological base:

> This is the central fact about 'infrastructuring' — it is not that the act of building an infrastructure ever simply ratifies pre-existing relationships: the act of infrastructuring changes what it is to be a road, a unit of currency or an ecology. Infrastructures are engines of ontological change. They stand between people and technology and nature and in so doing reconfigure each simultaneously. (Karasti et al., 2018, pp. 270-271)

Infrastructuring, therefore, focusses on the "doing and making" (Marttila & Botero, 2017, p. 103) of infrastructure; it emphasises the actual activities of the creators and users of an infrastructure, as opposed to what the infrastructure supports, and views such activity as integral to the infrastructure itself (Pipek & Wulf, 2009, p. 453). As discussed below, I wove this processual focus throughout my theoretical framework.

Thirdly, to investigate at once KI's scope and granularity, I used an approach termed *infrastructural inversion* which asserts that "understanding the nature of infrastructural work involves unfolding the political, ethical, and social choices that have been made throughout its development" (Bowker et al., 2010, p. 99). Limited space here precludes a longer discussion of infrastructural inversion – explained more thoroughly in Bowker (1994) and Bowker and Star, (1999) – but, methodologically, infrastructural inversion is widely used to tease out factors important to the development of KIs and consider their social effects, often employing ethnographic methods (Karasti et al., 2016a, p. 9). The notion of infrastructural inversion thus strongly shaped the investigative priorities of my study.

5. Theoretical framework and analysis of empirical data

In terms of *specific* aspects of KIs to focus on in my study, I started with a seminal list of dimensions of infrastructure (Star & Ruhleder, 1996) that has subsequently become foundational in the KI-literature (Edwards et al., 2013; Karasti et al., 2016a). Star and Ruhleder's (1996) eight dimensions underpin my thinking about KIs, but the theoretical framework I devised for this study is a distillation of the list into four categories. The table below reproduces Star and Ruhleder's (1996) original eight dimensions.

Table 1. The eight dimensions of infrastructure (reproduced verbatim from Star & Ruhleder, 1996, p. 113)

	Dimension	Definition
1	Embeddedness	Infrastructure is "sunk" into, inside of, other structures, social arrangements and technologies
2	Transparency	Infrastructure is transparent to use, in the sense that it does not have to be reinvented each time or assembled for each task, but invisibly supports those tasks
3	Reach or scope	This may be either spatial or temporal—infrastructure has reach beyond a single event or one-site practice
4	Learned as part of membership	Strangers and outsiders encounter infrastructure as a target object to be learned about. New participants acquire a naturalized familiarity with its objects as they become members
5	Links with conventions of practice	Infrastructure both shapes and is shaped by the conventions of a community of practice, e.g. the ways that cycles of day-night work are affected by and affect electrical power rates and needs
6	Embodiment of standards	Modified by scope and often by conflicting conventions, infrastructure takes on transparency by plugging into other infrastructures and tools in a standardized fashion
7	Built on an installed base	Infrastructure does not grow *de novo*: it wrestles with the "inertia of the installed base" and inherits strengths and limitations from that base
8	Becomes visible upon breakdown	The normally invisible quality of working infrastructure becomes visible when it breaks

The importance of Star and Ruhleder's list for KI-studies cannot be overstated, as it broke with conventional ideas

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of infrastructure as solid, unchanging and unremarkable while demonstrating infrastructure's complicated social and political nature (Jensen & Morita, 2017, p. 618). Twenty years after its publication, the principal themes of a four-part special volume of *Science & Technology Studies* devoted to KIs (Karasti et al., 2016a-d) – a volume that I take as representative of the contemporary field of KI-studies – still echoed these eight dimensions, especially as related to invisibility, labour, scale, values and performativity, along with KIs' emerging and relational characteristics.

In terms of helping to analyse my empirical data, however, I found Star and Ruhleder's (1996) list somewhat overlapping, so I synthesised the dimensions into four categories: Invisibility, Roots, Scale and Culturality. This synthesis is an original contribution to the KI-literature based on my exegesis of Star and Ruhleder's eight dimensions. In the discussion below, I illustrate each category with excerpts from my participants' interviews.

5.1 Invisibility

Firstly, the category of Invisibility comprises Star and Ruhleder's (1996) dimensions of *transparency* and *becomes visible upon breakdown*. My theoretical framework emphasised a range of invisibilities associated with KIs, including the invisibility of KIs in daily use, the mundane and unnoticed work of maintaining KIs and individuals' processes of making KIs visible (Karasti et al., 2016a, p. 8). KIs embody a range of (in)visibilities depending on perspective, with some, such as large-scale databases, designed to be spectacularly obvious. Invisibility, therefore, is a situated characteristic of KIs and a tool/tactic that can be wielded politically (Larkin, 2012, p. 336).

For my study, my theoretical framework was useful for delineating aspects of librarians' (in)visibility and the connection of invisibility with knowledge production. Throughout the data, for example, my participants discussed Twitter's utility in opposing stereotypes that foster the obfuscation of librarians' work. My participants related that these stereotypes, which caused a lack of visibility of their infrastructural contributions to university research – mainly in terms of provision of research support and digital databases – informed much of their tweeting:

> I think the main thing at the moment is that they've [faculty] got no grasp of the fact how much time, trouble and money and expense goes into providing the access to the digital resources they absolutely depend on. So, the perception is it's arriving on their desktop somehow and they don't really know and, like, see University of X on it, they don't realise that we've [librarians] got any input into that, they just tend to think of libraries as rooms full of books. (P2)

Moreover, my participants discussed Twitter's utility in facilitating access to users' digital spaces in an era of declining library-space usage. My participants related how a sense of invisibility impels them to 'be' in users' digital spaces to raise the visibility of librarians' work:

> If we don't do it [be on Twitter] that's not gonna stop researchers tweeting about open access, that's not gonna stop researchers tweeting about awful publishers' decisions, that's not gonna stop researchers tweeting about "Why is [the library catalogue] not helping me find the thing that I want…?" But if we're there, we have the opportunity to respond, we have the opportunity to sort of say, "Yeah, that's a fair point about open access. Have you seen the university's open access policy, have you seen our institutional repository?" Or "Yeah, this thing isn't working at the moment; come and talk to us and we'll give you a workaround." (P5)

In other words, the role of invisibility in my participants' Twitter practices, and its connection to knowledge production, is to provide justification for librarians' social media work, offering a rallying point around which to craft Twitter content. My theoretical framework was useful for exploring how my participants routinely probe the state of their (in)visibility within the institution and mobilise this feeling for political ends that then translate into knowledge production for the university.

5.2 Roots

Secondly, the category of Roots comprises Star and Ruhleder's (1996) dimensions of *embodiment of standards* and *built on an installed base* and draws attention to values at the foundation of KIs. My theoretical framework emphasised how the "values and ethical principles…we inscribe in the inner depths of the built information environment" (Star, 2002, p. 117) shape subsequent knowledge production.

For my study, my theoretical framework was useful for understanding the entanglement of professional values in my participants' Twitter work. Throughout the data, for example, my participants discussed how traditional librarian values of intellectual freedom (Gorman, 2015) are at the foundation of their Twitter practices. Twitter's utility in creating such futures is one of the promises (cf. Granjou & Walker, 2016; Larkin, 2018) of Twitter held closely by my participants:

> My real passion is getting research out of the silos of a particular research group or a particular faculty and out to as broad an audience as possible, and I think that librarianship is not necessarily the most showy way of doing that. But through helping people with publication, with open access, with putting things in a repository, with communicating their research on social media or blogs or designing conference posters, we can help people get their research out there in new and interesting ways, and in ways that are accessible. (P5)

Similarly, my participants related that the care and maintenance they devote to Twitter entails considerable attention to the production of scholarly online content – a desire, they feel, is grounded in librarians' ethics of neutrality and trustworthiness (Gorman, 2015). My participants interpret these professional values, however, in terms of their present-day contested and fraught positionality within the university and hopes for a more equitable future:

> I think that's part of my professional ethics. So, if you go by the CILIP [the UK professional organisation for librarians] professional ethics that we shouldn't censor information and we shouldn't pass judgement on information, we just deliver information, so it's just part of who I am as a librarian. … I'm very aware that, you know, we should always be not particularly presenting one side or the other, that it should be a dispassionate. (P2)

In other words, the role of roots in my participants' Twitter practices, and its connection to knowledge production, is to provide a foundation on which to determine credible online content. Such work, moreover, represents an effort to interpret traditional values of librarianship through the contemporary socio-technical context of HE. In this way, roots are not only connections to librarians' sense of traditional values, but anticipation of desired outcomes for the profession (Granjou & Walker, 2016).

5.3 Scale

Thirdly, the category of Scale comprises Star and Ruhleder's (1996) dimensions of *embeddedness* and *reach or scope* and draws attention to the micro and macro perspectives that infrastructural studies must simultaneously reflect. My theoretical framework emphasised that KIs exist at multiple scales simultaneously by perpetually evolving through processes of accretion (Anand, 2015) and having broad social effects beyond the local context of their creation. The methodological challenge for researchers, however, is gaining analytical purchase on phenomena with shifting boundaries and uneven growth (Karasti & Blomberg, 2018, pp. 238-239).

To address this challenge, I found two approaches particularly compelling. Firstly, Edwards et al. (2009) recommend focussing on how individuals "bridge scale" (p. 370) – e.g., through conceptualisations of how infrastructures *actually* work – to reconcile tensions between the promise/potential of infrastructure and its (inevitably) uneven integration into local practice. Secondly, Ribes (2014) recommends focusing on individuals' "scalar devices" (p. 158), or how people conceptualise and manage – e.g., through metrics or visualisations – the reach of their infrastructural efforts. For the purposes of my study, both approaches were useful for understanding the role of scale in librarians' knowledge production.

Throughout the data, for example, my participants discussed Twitter's tendency to grow in piecemeal fashion, reflecting how their one-tweet-at-a-time approach helps build relationships via Twitter. I argue that this sense of accretion is a way of bridging scale (Edwards et al., 2009), i.e., squaring the incremental, real-life effort of tweeting with the significant social networking that Twitter promises. In the process, this patient approach helps disseminate and reinforce my participants' scholarly content:

> Coming from a library point of view, you are often trying to get quite a bit of information across and that is a challenge. It's a challenge but I like a challenge, so I think that's why it's such a well-used medium of communication, I think, just because it's so short, clipped and neat. People get little packages of information. (P3)

Similarly, my participants related that the ultimate proof of their Twitter reach was conversations with followers on Twitter. Other forms of engagement, such as views and likes, were deemed less valuable. However, this gold standard of conversations – which I consider a scalar device (Ribes, 2014) to make manifest the boundaries of my participants' reach on Twitter – continuously leads to disappointment. The gap, in other words, between "engineered solution and social expectation" (Harvey, 2016, p. 52) was great:

> I'm really happy it's [a tweet] popular but I want *feedback*. I want to know how did that help you? What can you now do that you couldn't do before and are you going to tell people about this? So, there's the kind of selfish element there that I want to have actual conversations to know what people are thinking. But also, I think, there's an element that, I don't know, there's just the drive to go beyond broadcasting, to actually connect

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> with people. It's, sometimes you feel like you're shouting into the void with Twitter a little bit and just kind of hoping that someone will see it and pick up on it.

In other words, the role of scale in my participants' Twitter practices and its connection to knowledge production is to provide ways of understanding and managing the extent of librarians' Twitter activity. Approaches such as bridging scale (Edwards et al., 2009) and scalar devices (Ribes, 2014) demonstrate the valences of big and small in infrastructural work, revealing how growth of infrastructure and subsequent knowledge production is fuelled by local increments of work.

5.4 Culturality

Finally, the category of Culturality comprises Star and Ruhleder's (1996) dimensions of l*earned as part of membership* and *links with conventions of practice* and draws attention to how infrastructures and social practices are mutually constitutive. KIs, in other words, are "engines of ontological change" (Karasti et al., 2018, p. 271) producing subjectivities and community formations that, in turn, can further transform infrastructure (Jensen & Morita, 2017, pp. 619-620). From this perspective, knowledge production occurs via community transformation – and vice versa – and is a relationship that requires work to manage and sustain (Fenwick & Edwards, 2014).

For my study, my theoretical framework was useful for understanding the role of community formation in librarians' knowledge production via Twitter. Throughout the data, for example, my participants discussed their purposeful approach to creating connections between researchers via leveraging existing social networks. The hope was that such scholarly communities would increase the circulation of knowledge between researchers and promote potentially fruitful professional connections:

> It's not that I'm doing it [Twitter] with the primary purpose of promoting the library, although that's quite important right now. It's more that you can link things up, you can make … so as librarians we make connections between people, we do a lot of facilitating, we do a lot of getting different people to talk to each other who perhaps don't know they should be talking to each other, and you can do all of those things on Twitter. (P2)

Similarly, my participants discussed changes to professional identity and membership that working on Twitter produces. Specifically, they felt that working on Twitter leads to new vocational competencies and a sense of the interconnected community of librarians within the university, findings that accord with the new professional identities spurred by encounters with infrastructure identified by Jackson and Barbrow (2013):

> There are so many librarians here and it's such a great community, I think Twitter just enhances that. So, if for no other reason, even if I'm failing to be a great Twitter feed for [faculty] and for [my] library, at least having the Twitter feed means that sometimes I do talk to the other librarians and I'm supporting other librarians in what they're doing and whether that's having a good impact on their feeds, I don't really know, but I do think it helps support the community. (P2)

In other words, the role of culturality in my participants' Twitter practices and its connection to knowledge production is to promote connections between researchers, a process that helps create scholarly community and broadens the circulation of librarians' expertise. At the same time, such work on Twitter spurs new vocational identities amongst librarians in terms of fluency with Twitter's functionalities and a sense of professional interconnectedness.

5.5 Summary

In the sub-sections above, I summarised four aspects of academic librarians' knowledge production via social media tied to the categories of my theoretical framework. While there is overlap between the mechanisms – e.g., the cultural effect of making community stems from librarians' professional value of fostering community – each represents librarians' efforts to assert authority and expertise in a changing HE context. Such invisible work produces knowledge and is, in this sense, infrastructural, aligning with Edwards' (2010) definition of KIs as "networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds" (p. 17).

My theoretical framework, which utilised the tenets of infrastructural theory, enabled me to tease out this complicated context within HE. In the following section, I discuss how appreciation of this complexity, in terms of invisible labour, values, contingency, performativity and fragility of infrastructure, is crucial for understanding the use of technology in educational settings.

6. Infrastructural theory and technology-enhanced learning

In the field of TEL, despite the urging of C. Jones et al. (2006) to adopt more relational and social models of infrastructure, with few exceptions that I discuss below, most TEL studies of social media uncritically position infrastructure – if discussed at all – as support systems discrete from and in-service to teaching and learning practices. As Bayne (2015, p. 9) asserts, such black-boxing of infrastructure mutes its capabilities and renders it closed to investigation. In my review of studies of social media and TEL, I identified three ways that the inner workings of infrastructure are obfuscated or misunderstood. Firstly, infrastructure is posited as monolithic systems that need better resourcing for use in educational settings, exemplified by Chawinga's (2017 p. 16) discussion of Internet bandwidth problems on the African continent. Secondly, infrastructure is conceptualised as transparent systems that enable or constrain educational goals, exemplified by Greenhow and Lewin's (2016, p. 16) assertion that infrastructure inhibits students' use of social media in classroom settings. Thirdly, infrastructure is approached as algorithms that shape individuals' use of technology, exemplified by Fenwick's (2016, p. 671) discussion of regulatory codes that produce particular modes of communication on social media. Notwithstanding the social justice issues addressed by these studies, particularly those exemplified by the first and third approaches that highlight inequities and exploitation woven into social media platforms, all three studies posit infrastructure as a background bulwark to contend with and not a set of social practices with a degree of fluidity.

Even in TEL studies that explicitly acknowledge that social media is a set of practices shaped by infrastructure (Crook, 2012, p. 64), the mechanisms by which this happens are masked and not approached as imbrications of social and technical actors. I would argue that such conceptualisations of infrastructure are problematic for two reasons. First, positing infrastructure as monolithic support systems erases the myriad mundane practices that constitute infrastructures – practices that therefore make infrastructure contingent and often quite fragile – and diminishes not only efforts to design and maintain infrastructure but also individuals' capabilities to change or resist infrastructure (Jackson, 2014, 2015). Secondly, positing a dichotomy between teaching/learning and infrastructure erases ontological effects that working on and through infrastructure can bring, especially in terms of new identities and notions of community membership – particularly when such new subjectivities, in turn, can significantly change characteristics of the infrastructure (Jensen & Morita, 2017). I will return to both of these points in my discussion below about the implications of infrastructural theory for TEL.

Not all TEL studies posit infrastructure as monolithic bulwarks, however. A handful explicitly use relational and social models of infrastructure derived from Star and Ruhleder's (1996) framework and thus provide alternative approaches. These studies are generally concerned with the relationship between micro-level practices and wider social phenomena, often linked conceptually via a middle or meso layer (C. Jones et al., 2006). In particular, with a view to determining the best settings for TEL, such studies attempt to untangle the socio-political-technical factors impeding or enabling implementation of new educational technologies (C. Jones, 2015). In these studies, infrastructure is often defined as assemblages of resources – social, technical, institutional – that support educational practices (Bygholm & Nyvang, 2009; Guribye, 2015; Guribye & Lindstrom, 2009; C. Jones et al., 2006). As C. Jones et al. (2006) assert, "infrastructures are the working out of institutional processes *in relation to* available technologies" (p. 44, emphasis added). Infrastructure in these studies is not given *a priori* but relational to educational practices. For this reason, Guribye (2015, p. 195) argues that approaching "large-scale learning environments" such as MOOCs or learning analytics from an infrastructural perspective affords openings to investigate them ethnographically and situationally. Read (2019) further asserts that if infrastructure, such as learning management systems, are only *infrastructural* in relation to existing practices, then this creates opportunities to consider inextricable relationships between culture and infrastructure, i.e., how infrastructure is constitutive of socialities and vice versa.

Moreover, in contradistinction to studies that posit infrastructure as monolithic support systems, TEL studies that use relational and social approaches to infrastructure acknowledge a significant degree of *agency* in individuals' interactions with infrastructure. DeVoss et al. (2005) for example emphasises that an infrastructural perspective is useful to "identify access points for discursive agency and change-making within institutions" (p. 19). C. Jones (2015) also draws attention to the role of users in building infrastructures, though his focus on path dependencies and the role of digital infrastructures in shaping learners (pp. 142-144) perhaps diminishes human agency to create and change infrastructure. Lenstra and Baker (2017) propose a thought-provoking model of human agency in information infrastructure, asserting that intermediaries – in their case, librarians, though the model could be extended to learning technologists and curriculum designers – help bridge

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infrastructures and communities, thus giving individuals a voice in infrastructural development and change.

For the purposes of this article, TEL studies that explicitly use a social and relational view of infrastructure are useful for illuminating the context in which teaching and learning occurs, emphasising that technologies do not inherently enhance education and that existing social and technical arrangements significantly shape TEL practices. Such holistic perspectives are useful for countering the prevalence of micro-level, localist studies in TEL (Crook, 2019; Jameson, 2019), moving as Monteiro et al., (2013) remark "from artefacts to infrastructures" (p. 575).

However, despite these excellent studies, I would argue that social and relational approaches to infrastructure in TEL studies could be strengthened further by integrating two tenets of infrastructural theory emphasised in my theoretical framework. The first is Star's (2002, p. 110) contention that to understand infrastructure, it is necessary to study its "boring" parts such as the values and ethics woven into the mundane practices of designing and maintaining infrastructure. A focus on the "doing and making" (Marttila & Botero, 2017, p. 103) of infrastructure, i.e., its infrastructuring (as discussed in Section 4), highlights its behind-the-scenes labour and power distributions (Blok, 2016, p. 17), drawing attention to infrastructure's often remarkable fragility and contingency. The second tenet of infrastructural theory is its insistence on the ontological effects of infrastructure, particularly infrastructure's role in shaping socialities (such as community groupings) and subjectivities (such as professional identity) – and, importantly, how such formations can, in turn, influence the dynamics of infrastructure (Jensen & Morita, 2017, p. 620). In other words, there are aspects of infrastructure that have not been fully theorised in the TEL literature which would benefit from perspectives of infrastructure articulated in STS and cultural anthropology. The few TEL studies that employ social and relational approaches to infrastructure are important alternatives to viewing infrastructure as monolithic forces, but none analyse infrastructure from the perspective of the people who design and maintain infrastructure, a perspective I feel is crucial for understanding and improving TEL practices. Based on this admittedly brief review of TEL literature and lacunae in TEL theory, there are two broad implications of infrastructural theory for TEL that I would like to discuss.

6.1 Acknowledging agency

The first implication of infrastructural theory for TEL is to challenge simplistic depictions of infrastructure as analytically separate from – or even in opposition to – learning contexts. A social and relational view of infrastructure means that infrastructure is determined through use and that, therefore, learning communities develop *in* and *through* infrastructure, not separate from it (Guribye, 2015; Read, 2019). Moreover, the ontological focus that I have emphasised throughout my theoretical framework posits a mutually constitutive relationship between individuals and infrastructure. From this perspective, infrastructure is not *a priori* steeped in systems of politics (e.g, neoliberalism) that unilaterally exert a force on users. Infrastructure is contingent, comprised of a myriad of individuals' decisions and with performative effects on socialities and agencies, *which in turn* can affect the nature of the infrastructure (Jensen & Morita, 2017, p. 620). Infrastructure, therefore, does not present a monolithic us/them binary. Consequently, if infrastructure is a fragile accomplishment rooted in individuals' practices, then perhaps seemingly unassailable systems – such as learning analytics, VLEs and MOOCs – are not nearly as powerful or permanent as we might concede (Jackson, 2014, 2015). An infrastructural perspective thus affords the ability to see systems as contingent, malleable and, ultimately, ephemeral – or not – but the infrastructural perspective allows for these possibilities. As Appel et al. (2018) contend, when scrutinising infrastructure "an attention to the practices of low- and mid-level administrators and technicians challenges any easy characterizations of technopolitics as exercised from afar" (p. 13). In other words, understanding the "pedagogical choices" (Guribye, 2015, p. 190) woven into infrastructures can better enable educators to negotiate or contest infrastructures that support TEL: "If infrastructures are conceived of experimental systems that generate emergent practical ontologies, then the shape of politics and power is one of the outcomes of infrastructural experiments" (Jensen & Morita, 2017, p. 620).

6.2 Bringing multiplicity into focus

The second implication of infrastructural theory for TEL is its capacity to "bring multiplicity into focus" (Blok et al., 2016, p. 2). By multiplicity, I mean that infrastructural theory foregrounds assemblages of social phenomena, material conditions and institutional arrangements that support TEL, as well as the performative social effects infrastructures can shape. By its very nature, therefore, infrastructural theory embraces heterogeneity. Infrastructural theory is a theoretical approach to research that does not black-box the arrangements that support TEL. Instead, it prioritises the role of values and ethics in the design and use of infrastructural resources and the performative social effects infrastructure can shape. Using infrastructural theory is thus a means of moving away from purely localist studies in TEL and embracing concern for individuals' situated and

evolving contexts. As discussed earlier, infrastructural theory focuses on the meso layer, but also helps reveal the inherent porosity of the meso, as aspects of micro and macro levels can be mutually constitutive. An infrastructural focus thus draws our attention to the "rich, multifaceted relations between humans and things" (Jackson, 2015), emphasising the care and repair involved in maintaining infrastructure such as attachments to past practices or hopes for the future (Stuedahl et al., 2016).

6.3 Summary

Drawing the discussion back to the use of social media in HE for pedagogical and research purposes, my focus on librarians' work behind the scenes to construct educational Twitter feeds helps complicate notions of infrastructural support in HE, making such support easier to understand, negotiate and contest. Infrastructure that supports TEL settings is, thus, not a sinister bulwark to contend with, removed and sealed off from human activity. Instead, infrastructure is inextricably intertwined with learning activities and productive of knowledge and subjectivities (Fenwick & Edwards, 2014). Therefore, studies that focus solely on 'what works' implementations of social media in HE and disregard larger infrastructural concerns miss crucial aspects of educational settings. As Star asserts, "study an information system and neglect its standards, wires and settings, and you miss equally essential aspects of aesthetics, justice, and change" (p. 117). Seen in this light, people are not passive recipients of infrastructure but its productive actors (Blok et al., 2016, p. 17). As my study has exemplified, KIs – and, by extension, infrastructures generally – are not merely background support systems, but constituted of individuals' practices and sites for negotiations of values and tensions (Karasti et al., 2016c, p. 4). I contend that exploring these largely invisible material conditions of knowledge production is crucial for appreciating the nature and possibilities of social media in the contemporary HE context. As Simonsen et al. (2019) summarise, "infrastructure as a relational phenomenon is interdependent and inextricably connected with forming complex and extended socio-material-technical-political constellations" (p. 6).

7. Conclusion

In this reflexive paper, I discussed how tenets of infrastructural theory from the fields of STS and cultural anthropology were useful for explaining how academic librarians produce knowledge for HE via social media. Extrapolating this focus more widely to TEL, my theoretical framework also helps illuminate the agency and multiplicity inherent in infrastructure – a phenomenon frequently conceptualised in TEL studies (as discussed in Section 6) as monolithic and separate from social practice. My framework thus provides a vocabulary for making visible the human work and values at the heart of infrastructures for TEL (cf. Hine, 2020; Johanes & Thille, 2019; Seaver, 2018), helping shift discussions from what infrastructure invisibly supports to what it constitutes socially. The formulation of infrastructure presented in this paper lead me, therefore, to make two recommendations:

Firstly, Bodily et al. (2019) and Bond et al. (2019) both note that studies of educational technology need more robust design interventions for determining optimal conditions for teaching and learning. Employing an infrastructural perspective is valuable therefore for providing crucial contextual focus to design considerations. I concur with Guribye's (2015) assertion that

> Embracing this understanding of infrastructures as relational to educational practices also requires that we take a different view of design, examining the interconnections and seeing technical, social, and institutional arrangements as part of the object of design. (p. 194)

From this perspective, therefore, infrastructure is an inherent aspect of individuals' social practices (Star, 2002, p. 116) and worthy of more than cursory or despairing analyses. Encouraging critical reflection on the underlying work to create and maintain infrastructure, moreover – and not relying on organisational fictions about such work – naturally leads to better overall designs for environments that support human practices such as teaching and learning (Suchman, 1995).

Secondly, the time seems ripe, given more than 20 years of robust research on the nature of infrastructure in the fields of STS and cultural anthropology, for fuller theorisation of infrastructure in TEL. The growing imperative of grasping how large systems such as learning analytics, for example, shape contexts for teaching and learning (Williamson, 2017, 2018) makes this an urgent concern. A first step would be a thorough review of conceptualisations of infrastructure in the TEL literature. We then need further studies that explore the imbrication of infrastructural concerns in activities of teaching and learning. At a minimum, such work would encourage approaching infrastructure as complex phenomena entailing a degree of agency, contingency and fragility and not separate from, or monolithically in opposition to, concerns of teaching and learning.

Crook (2019), however, expresses concern about "idiosyncratic theory bubbles" (p. 486) in TEL from outside

the field of education that do not foreground teaching and learning. This is a valid concern, naturally, but I believe that using infrastructural theory in conjunction with existing educational theories would be valuable for its explicit concern with illuminating the socio-political-technical contexts of human practices. We should, however, be wary of using 'infrastructure' as a buzzword without defining it explicitly (Edwards et al., 2011, p. 1412) and alert to overusing the concept (Lee & Schmidt, 2018). On the other hand, given the centrality of cloud systems, big data, digital privacy issues and other aspects of Internet technologies for TEL, foregrounding infrastructure and theorising its relationship to contexts of teaching and learning seems essential (Ludvigsen & Steier, 2019). As Karasti et al. (2016a) argue, studies of infrastructure, and knowledge infrastructures particularly, can "present new ways of creating, generating, sharing, and disputing knowledge and explore the altered mechanics of knowledge production and circulation (p. 6)." Such concerns are vital to TEL moving into the third decade of the 21st-century.

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